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Technological and economic evaluation of conversion of potential flare gas to electricity in Nigeria

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Abstract

Globally, over 100 billion cubic metres (BCM) of gas is flared annually and, this is linked to an annual emission of 400 million tons of carbon dioxide. In Nigeria the annual gas production is valued at 33.21 BCM, out of which more than 50% is wasted through flaring, thereby emitting about 35 million tons of carbon dioxide. About 14.94 BCM of gas produced in Nigeria is used for a variety of activities including electricity generation. Despite this scenario, Nigeria is still unable to generate and distribute enough electricity for the citizenry. This paper therefore evaluates the use of gas to wire technology as the option to minimise gas flaring in Nigeria while minimising the associated environmental impacts. The research methodology was based on interviewing top level managers in an electricity generation company, and gas Production Company, as well as the researchers' site observations within the two case companies. Results from this study showed that electricity generation could be improved from its current daily production rate of 4358 MW to about 12000 MW from the use of part of 18.27 BCM of gas flared annually in Nigeria. This serves as fuel for 50 units of gas turbine with power output of 150 MW each, with a potential increase in daily electricity generation of 7500 MW.

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Keywords: Gas to Electricity; Gas Turbines; Gas Flare Reduction; Nigeria

1. Introduction

Gas flare activities take place during oil exploration processes for disposal of associated gas, basically for safety and operational reasons. Nevertheless, the past 3 – 5 decades have experienced global awareness towards natural gas sustainability and the environmental concerns.

According to World Bank [1], the year 2015 witnessed about 147 BCM of global gas flare, even though there is reduction in quantities flared by the six countries mainly responsible for this practice (Figure 1). Russia is top on the list with 21 BCM, and Nigeria flaring about 8 BCM in a given year. However, it is noteworthy that on average, about 50% of the total gas produced in Nigeria is practically flared [2].

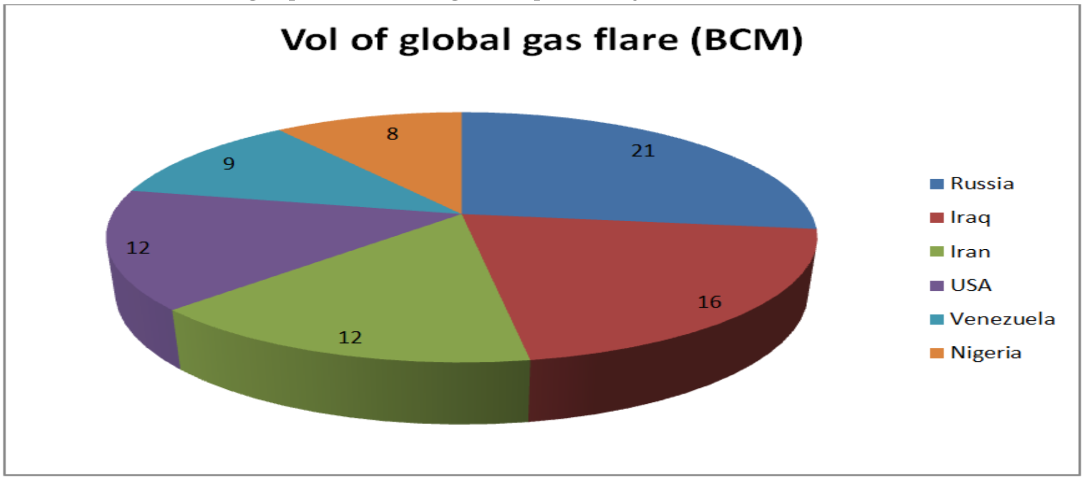

Figure 1: Top six gas flaring countries [1]

Nigeria has an estimated reserve of natural gas of 5.3 trillion cubic meters (187 trillion cubic feet) [3, 4]. Its annual production of gas is 33.21 BCM, annual gas utilized is 14.94 BCM and the annual flared gas averages 18.27 BCM [5]. Gas flare is associated with environmental, economic and health impacts and it is responsible for the release of about 300 million tons of CO_2 per year into the environment [6], as well as pollution of the environment by other greenhouse gases. It also destabilizes the ecology, and according to British Petroleum [7], Nigeria losses $2.5 billion annually due to gas flare during oil and gas processing.

In this study, the use of potential flare gas has been highlighted as a means to generate electricity and, preliminary study has reviewed the technological and economic implications of the use of this GTW technology for electricity generation, particularly in Nigeria.

2. Literature review

2.1 Gas flare reduction through gas-to-wire technology

Electricity generation with power cycle is one of the methods suitable for systemic reduction and or elimination of gas flare. The basic principle of the power cycle requires use of gas turbine (GT) to produce electricity. Gas turbines are increasingly used for electricity generation especially where substantial quantities of natural gas are abundant [6, 8]. Turbines generate high power outputs at high efficiencies and low emissions and can also be used in simple cycle mode for base load mechanical power and electricity generation in the oil and gas sector where natural gas and process gases have been used as fuel; and their maintenance costs are much lower than those for liquid fuels. According to Meetham [9], the gas turbine has its advantages, which include the following:

- Fuel flexibility: the gas turbine has the capability to burn various qualities of gases than other reciprocating engines.
- Few number of moving parts (cheaper cost of maintenance with few moving parts).
- High availability.
- Less vibration and noise.
- It is compact.

Figure 2 shows the Brayton cycle, which is one of the most efficient cycles for the conversion of gas fuels to electricity [10]. It shows that air enters the compressor from the atmosphere as the pressure is increased from atmospheric pressure to 23 bars. Compressed air later moves to a combustion chamber and then mixes with natural gas as combustion takes place. At point 3 of the cycle, hot gases are directed to the gas turbine where they expand to the atmospheric pressure and gas energy is converted to mechanical energy which generates electricity. Exhausted gases are subsequently discharged from the gas turbine thereafter.

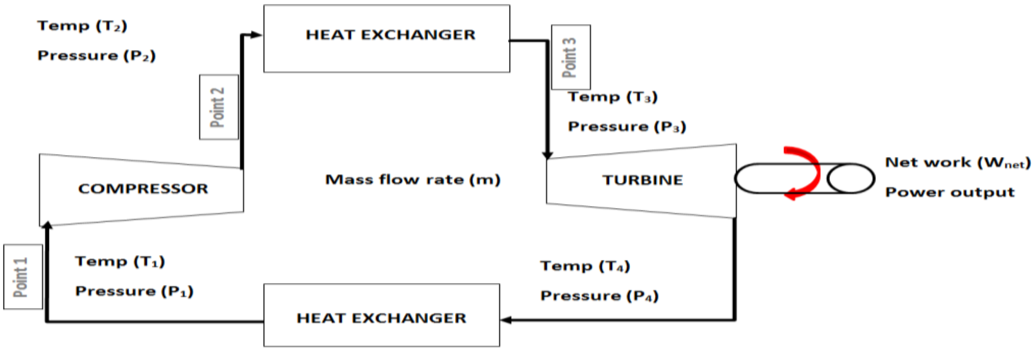

Figure 2: A Flowchart of the Brayton Cycle (Adapted from Rahimpour *et al.* [8]

Figure 3 shows the temperature versus specific entropy (T-S) diagram, which is a conceptual thermodynamic cycle made up of a very small set of components. This cycle could either be an open gas turbine cycle or a closed gas turbine cycle; and is made up of two adiabatic and two constant processes. It also involves four processes, with either a gas or a mixture of gases as working fluid. The first process is known as an adiabatic compression, the second process is the heat supply at constant pressure, the third process is an adiabatic expansion, and the fourth process is known as a release heat at constant pressure.

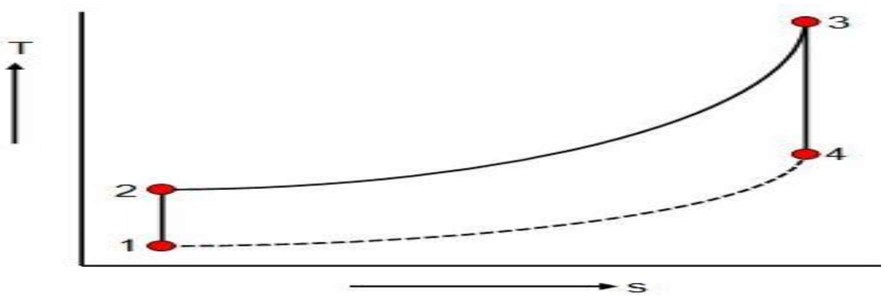

Figure 3: T – S Diagram illustrating the stages in Joule-Brayton Cycle [11]

The use of GTW technology for gas flare reduction has been simulated in a refinery environment in Iran by Rahimpour *et al.* [8]. It showed that the estimated capital investment is high; however, it also showed that the rate of return of investment is high. Their simulation was carried out using gas flow rate of 356.5 million standard cubic feet of gas per day (MMSCFD) into the turbine. This process produced 2130 MW of electricity daily. Therefore, GTW could be a way forward for gas flare minimization, which also comes along with financial incentives from sales of electricity.

3. Methodology

Data for this study was collected using semi structured interviews from five highly placed members of staff from three specially chosen companies. These include two electricity generation and distribution companies (ELEGEN 1 & 2), and one gas production and flaring firm (GASPROC). The interviewees from these case companies were chosen based on their knowledge and experience on gas flaring and electricity generation. This enabled the study to establish gas to wire technology as effective means of gas flare reduction, particularly in Nigeria. Table 1 shows profile of key staff interviewed for the study as well as their levels of experience in the industry.

Table 1: Demographics of Key Personnel from the Interviews

Case company	Key personnel	Years of experience
ELEGEN 1	Power plant operator	11
	Operations and maintenance manager	18
	Electrical maintenance repairer	12
	Technical manager	6
	Shift supervisor	22
ELEGEN 2	Power plant operator	10
	Operations and maintenance manager	5
	Electrical maintenance repairer	16
	Technical manager	2
	Shift supervisor	7
GASPROC	Production manager	20
	Health and safety manager	23
	Operations supervisor	15
	Field operator 1	22
	Field operator 2	10

This study also used secondary data from official company documents such as Minutes of meetings, administrative documents, and progress reports, newspaper articles from the case companies. This source of data collection helped towards provision of reports concerning plant inspection, equipment status, workflow, and staff strength within these case companies.

Qualitative data analysis was carried out using the NVivo software. The collected data was coded into nodes and put into categories which covered major areas of concern such as gas production, utilisation, flaring, and impediments to gas to wire technology. Categories were further grouped into themes such as gas flare management and gas production and utilisation themes.

4. Discussions

The gas production and utilisation subsection of the discussion highlights the volume of gas produced and flared by GASPROC, and utilised by ELEGEN 1 & 2; while the second subsection addresses the major factors inhibiting effective application of gas to wire technology in Nigeria.

4.1 Electricity Generation in Nigeria Using Gas to Wire Technology

This technology involves a linkage of processes which include gas gathering and transportation system (which involves pipelines), processing plant, storage facilities (reservoir to contain gas), and the gas turbine for electricity generation. Figure 4 shows the sequence of activities for gathering and utilisation of the flare gas. As a routine during oil exploration, the associated natural gas is mostly wasted either through flaring or venting. However, instead of wasting the gas, the proposal is to gather the waste gas in a reservoir through pipelines and then subsequently supplied to the power station for electricity generation, while any excess is converted to liquefied natural gas (LNG).

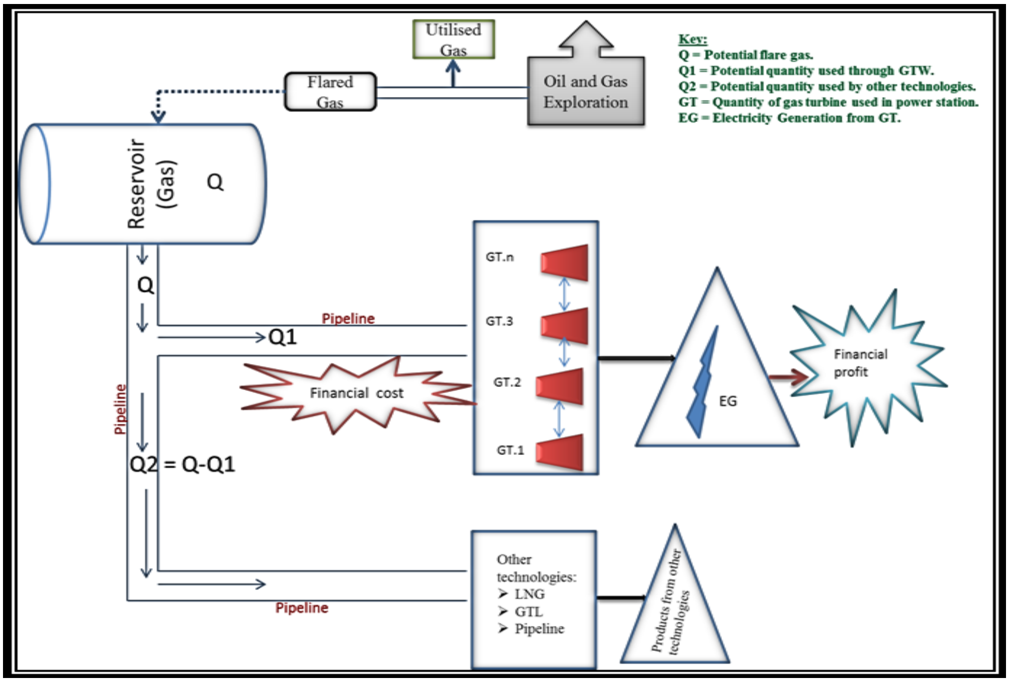

Figure 4: Flow chart showing gathering and utilization of flare gas

4.2 Gas production, flaring, and utilisation with GASPROC and ELEGEN 1 & 2

The daily gas production by GASPROC is 240 million standard cubic feet (mmscfd). 50 mmscfd and 120 mmscfd of gas are supplied to ELEGEN 1 & 2 respectively for electricity generation; while 50 mmscfd is delivered to a third organisation through pipeline. Ironically, GASPROC flares 20 mmscf of gas daily which could increase depending on requirements by ELEGEN 1 & 2; although, in a situation whereby the demand is less, there is a regulatory feedback system which signals the gas production plant to minimise production in order to minimise flaring.

Further data collection from this study showed that the current annual gas production in Nigeria is 33.21BCM; gas utilisation is 14.94 BCM, while the flaring is 18.27 BCM. It is also inconceivable that despite the huge volume of gas flared, Nigeria still faces poor electricity generation. The average daily electricity demand is 12,000 MW, whereas the current electricity generated is about 4,358 MW.

4.3 *Barriers to gas to wire technology*

The gas to wire technology seems an ideal solution to achieve gas flare reduction in Nigeria, while boosting electricity generation and distribution; however, it still faces several challenges. Inefficient gas utilisation, reduction in gas utilisation by power stations, plant shutdown, separation of condensate, plant overhaul, lack of funds, lack of spare parts, lack of trained local maintenance engineers or personnel, irregular gas supply, presence of faulty turbines in power stations, lack of turbine maintenance are the major factors that were identified by this study that inhibit the effective application of GTW technology, especially in Nigeria.

4.4 Financial Attachment of GTW technology

An economic evaluation of adopting GTW technology for electricity generation in Nigeria was carried out using the ALSTOM GT13E2 turbine, whose performance parameters are stated in Table 2.

Table 2: Primary performance parameters for GT13E2 [12]

Fuel	Natural Gas
Frequency	50 Hz
Gross Electricity Output	150 MW
Gross Electricity Efficiency	36.4%
Thermal Efficiency	36%
Turbine Speed	3000 rpm
Fuel Gas Temperature	31 ^{o}C

A unit of ALSTOM GT13E2 consumes a total of 0.93 million cubic meters (mcm) of gas per day and generates 150 MW of electricity. This information enabled economic estimation of the potential to adopt GTW for electricity generation, and gas flare reduction in Nigeria. According to Table 3, it is feasible that 16.97 billion cubic metres (BCM) of gas could be utilised to generate extra 7,500 MW of electricity per annum, using 50 units of turbines. The key driver is the availability of gas, but since the volume required for this operation is lower than the average yearly gas flare in Nigeria, there should potentially be no issue with enough gas supply.

Table 3: Estimated Gas Usage and Electricity Generation in Nigeria Using GTW Technology

No. of Gas Turbine (150 MW Capacity/Turbine)	Daily Gas Usage (M^3)	Daily Electricity Gen. (MW)	Yearly Gas Usage (M^3)	Yearly Electricity Gen. (MW)
1	930,000	150	339,450,000	54,750
2	1,860,000	300	678,900,000	109,500
5	4,650,000	750	1,697,250,000	273,750
10	9,300,000	1,500	3,394,500,000	547,500
20	18,600,000	3000	6,789,000,000	1,095,000
30	27,900,000	4,500	10,183,500,000	1,642,500
40	37,200,000	6,000	13,578,000,000	2,190,000
50	16,972,500,000	7,500	16,972,500,000	2,737,500

Tables 4 and 5 demonstrate the economic implication of the application of GTW technology in Nigeria, using the factors stated earlier such as units of turbine, amount of generated energy, and volume of gas utilised. Table 4 highlights that the major capital investment goes into acquisition of equipment such as turbines, spare parts, as well as inflation cost. The total estimation for capital investment in Nigeria is £1,643,185,000.

Table 4: Estimated Capital Investment for a Nigerian Power Plant

DESCRIPTION	COST (£)
Equipment (50 Units of Gas Turbine)	1,051,575,000 (140.210/kw)
Installations of equipment and Piping	360,900,000
Maintenance/Working Cost.	230,610,000/year
Royal to Host Community	100,000
Total capital investment	1,643,185,000

4.5 Estimated electricity generation and financial output

It appears that residential tariff system is commonly used in Nigeria, where a kWh of electricity costs £0.07. Therefore, it was utilised as a basis for the calculation for income from sales of electricity. Based on this, a calculation is provided to demonstrate the financial output from a unit of turbine at 150 MW capacity each.

1 MW = 1000KW

A unit of gas turbine capacity of 150 MW is equivalent to 150,000 KW:

Cost of electricity per KWh in Nigeria = £0.07

So, daily income from operating one turbine = 150,000 x 0.07 = £10,500

And yearly income per turbine = £10,500 x 365 = £3,832,500

However, since this is gross income, net of operating / maintenance costs would be much less than this figure.

Subsequently, this study considered some variables as seen in Table 5, which were applied towards estimated financial income.

The significance from this economic assessment includes huge financial investment requirement of about £1.6b for an estimated capital investment; however, on a yearly basis, the investment potentially generates a net profit of £1.2b, which could be attributed to cost of electricity in Nigeria (£0.07 per kWh); very high amount of electricity produced from the turbines and; high demand of electricity in Nigeria. Also the period of return on investment (ROI) is a positive motivation for potential investors because recuperation of the capital investment should be about 6 years.

5. Conclusion

This study concludes by presenting some recommendations that encourage utilization of gas to wire technology, to reduce waste and its associated environmental impacts in Nigeria:

- Provision of more power stations and gas turbine units, in various locations of Nigeria. There is the need to have these power stations in many different locations in Nigeria considering the high levels of power outages in the country.
- Gas supply should be improved, as this will create a meaningful contribution to electricity generation in Nigeria.
- Power lines should be updated and high voltage overhead lines changed to underground lines if possible.

- Surveillance team should be put in place along pipeline routes to manage vandalism and bush burning.
- Transformers should be regularly maintained to renew / replace old/weak transformers.
- Encouraging regular line patrol.
- Checking and discouraging illegal electricity wire connections.
- Stocking of spare parts to ensure turbines and plants can easily be replaced as at when due.

Table 5: Estimated Income and Return Cost Statement.

Caption	Value
(a): Cost of sale of electricity	£0.07/kwh
(b): Total cost of electricity sale/year	£4,599,000,000
(c): Product Cost for turbines operation	£0.007/kWh
(d): Total product cost for turbines/year	£459,900,000
(e): Fixed Charges	£689,850,000/Year
(f): Break-even Point Capacity	10,950,000,000 kWh
(g): Yearly income in B.E.P Capacity	£766,500,000
(h): Capacity of turbines Per Year	65,700,000,000 kWh
(i): Total Cost	£2,792,935,000
(j): Total Yearly Income	£4,599,000,000
(k): Gross Profit	£1,806,065,000/year
(l): Net Profit	£1,264,245,500/year
(m): ROI	16.3%/year

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